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Deep water property variations below about 4000 m in the Shikoku Basin*

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Abstract: Time series of spatial distributions of potential temperature and dissolved oxygen concentration below 3800 m in the Shikoku Basin during 1975-1983 are described. It seems likely that there is a steady or unsteady northward flow below about 4000 m along the western boundary of the basin; possibly it circulates clockwise off the continental slope slowly moving upward and renewing the deep basin water. In 1976-1977 an anomalously cold deep or bottom water with corresponding high oxygen values intruded into the basin. However, a remarkable increase in dissolved oxygen that occurred up to 3000 m or less in 1980-1982 was accompanied only by a subtle decrease in potential temperature. The direct source of such an anomalously cold or oxygen-rich deep water can be traced at least 15°N; at 4000 m level it may travel from 15°N to 30°N in about one year. The transient sharp decrease in dissolved oxygen that took place at least below 2000 m in the eastern area north of 20°N during the period of the second half of 1981 to early 1982 must be connected with the occurrence of the southward shift of the Kuroshio path in November 1981.

1. Introduction

The Shikoku Basin is a small basin with depths of 4000 to 5000 m located in the northeastern corner of the Philippine Sea. It shapes like a triangle. It is bounded on the north by the continental slope running from west-southwest to east-northeast. The eastern boundary is the Izu-Ogasawara Ridge of less than 3000 m in depth. On the southwest, though the bottom topography is much complicated, the Kyushu-Palau Ridge extends southward separating the Philippine Basin from the Shikoku Basin. To the south it connects with the West Mariana Basin at 25° to 26°N (Fig. 1).

It is considered that the deep water below about 4000 m in the Shikoku Basin has entered the West Mariana Basin through a rift (about 11°N, 141°E) southwest of the Mariana Ridge and has spread northward. The sill depth is estimated to be about 4500 m. The uniformity in deep water properties below a depth of 4500 to 5000 m in the Shikoku Basin has implied that the water renewal is less significant within a few hundred to a thousand meters of the bottom.

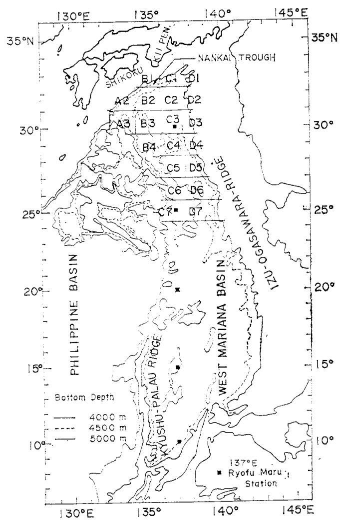

Fig. 1. Bottom topography south of Japan and the division of the Shikoku Basin used in Figs. 2 and 3. Area symbols and boundaries are as follows:
132°40′E [A] 134°20′E [B] 136°00′E [C] 137°40′E [D] Izu-Ogasawara Ridge,
24°20′N [7] 25°40′N [6] 27°00′N [5] 28°20′N [4] 29°40′N [3] 31°00′N [2] 32°20′N [1] continental slope.

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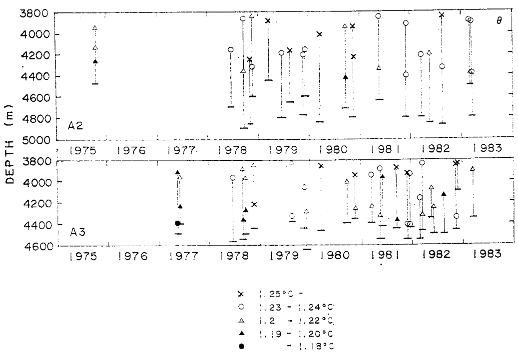

Fig. 2-1. The space-time distribution of potential temperature between 3800 m and the bottom during the period 1975–1983. Short horizontal bars denote bottom depths. Area C6 is excluded because of the complete lack of observations.

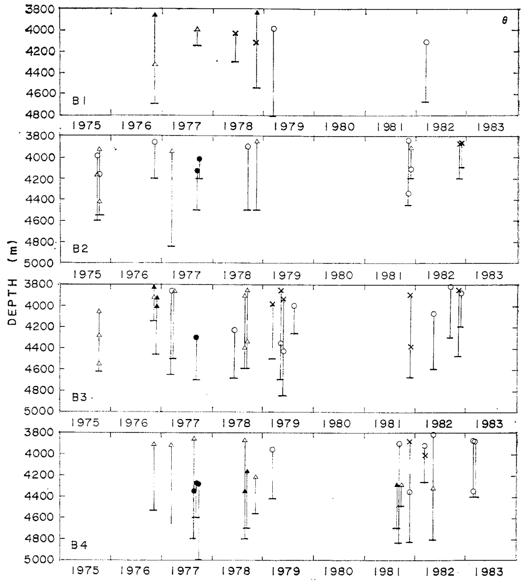

Fig. 2-2.

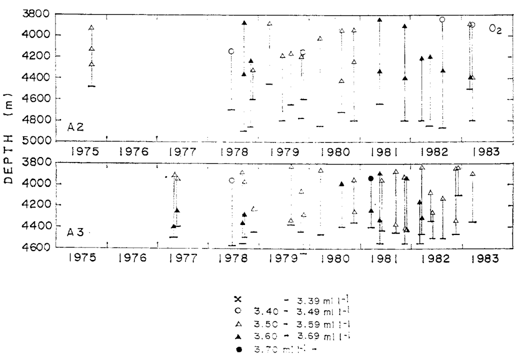

Fig. 3-1. As in Fig. 2. except for dissolved oxygen concentration.

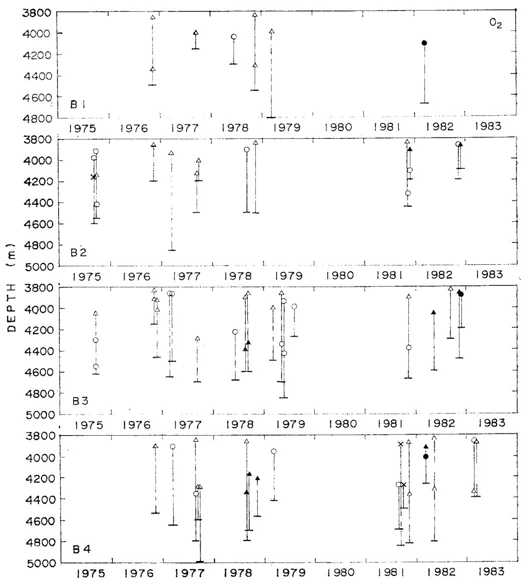

Fig. 3-2.

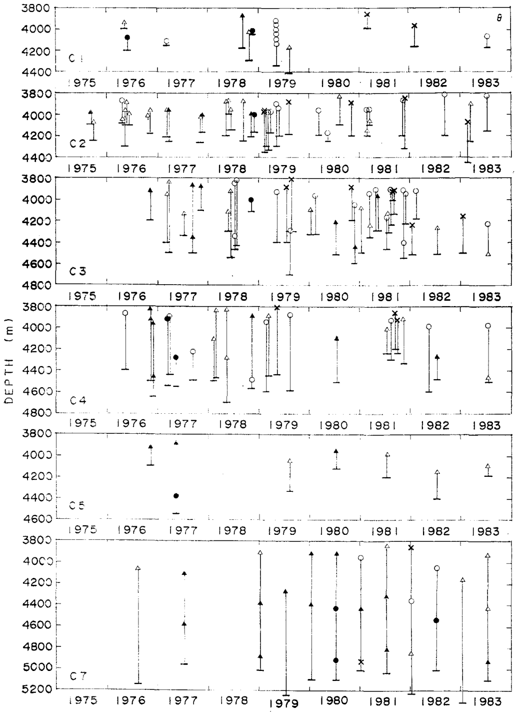

Fig. 2-3.

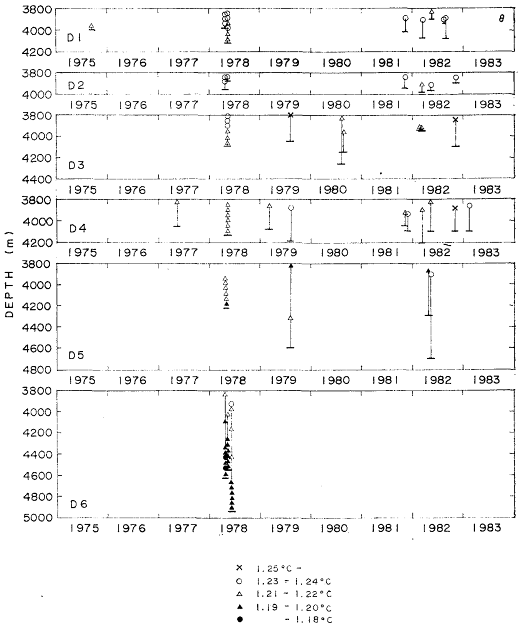

Fig. 2-4.

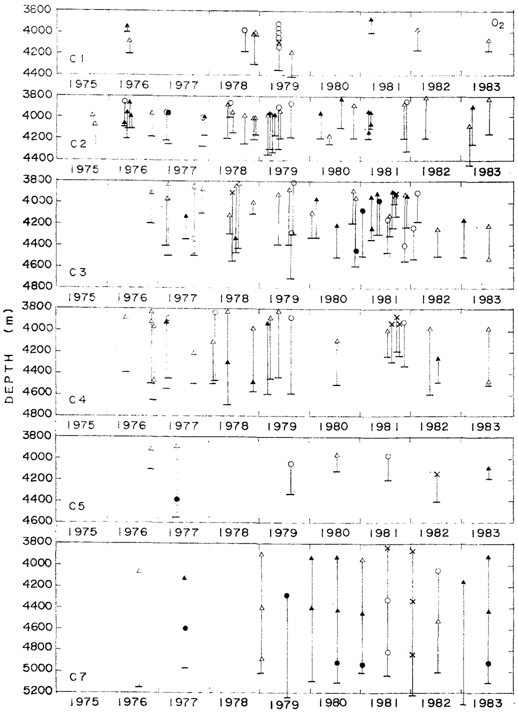

Fig. 3-3.

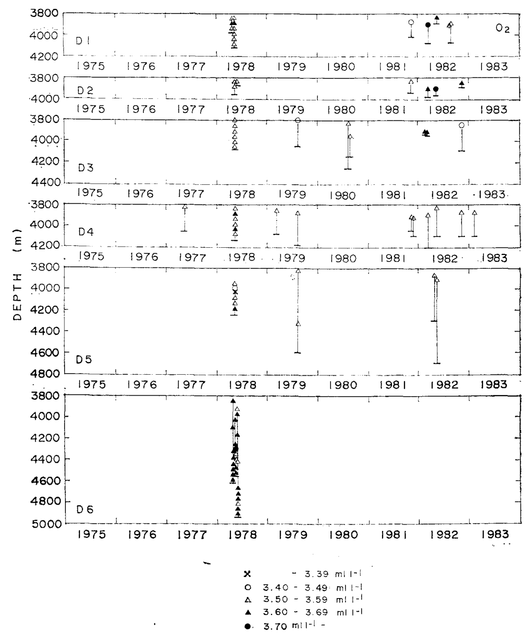

Fig. 3-4.

A few direct current measurements and CTD observations suggest that there is a cyclonic gyre below about 3000 m in the northern part of the Shikoku Basin (FUKASAWA *et al.*, 1985).

In 1976, to cope with the southward detour of the Kuroshio path, the Hydrographic Department, Maritime Safety Agency, started regular hydrographic casts down to about 3000 m or more in the area south of Shikoku and Kii Peninsula. Though the vertical sampling at every 500 m was not adequate to the analysis, it was shown that below about 4000 m the water was apparently cooler for a time in 1976–1977 (SUDO, 1982). Unfortunately, salinities obtained from some cruises might include excessive systematic errors for the deep water. Therefore, in the present analysis, an attempt is made to examine mainly temperature and dissolved oxygen variations below about 4000 m in the Shikoku Basin.

2. Distribution of potential temperature and dissolved oxygen collected below 3800 m

The quarterly hydrographic survey on R. V. *Takuyo* or *Shoyo* of the Hydrographic Department has been carried out in the area north of 28°N between 132°E and 139°E since 1976. Neither fixed sections nor fixed stations have not been set. For every cruise hydrographic casts were made usually on about 30 stations, among which less than 20 had casts extending to depths greater than 3000 m and about ten or less to 4000 m or more. A section along 137°E has been occupied by R.V. *Ryofu Maru* of the Japan Meteorological Agency in winter since 1967 and repeated in early summer since 1973. In general, its deep hydrographic casts down to 4000 m or more were made at every five degrees of latitude and occasionally at every one degree north of 28°N for summer cruises. For both routine observations, vertical spacing was usually 500 m for depths greater than 2000 m. In addition, there are some available hydrographic data: *Hakuho Maru* Cruise KH-75-5 in September–October 1975 (OCEAN RESEARCH INSTITUTE, 1978), INDOPAC Expedition Leg II in May 1976 (SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1978) and *Kaiyo Maru* cruises in May 1978 and May 1979 (SUDO, 1979). These samples were closely spaced in vertical, at every 200 to 300 m or less.

It is advisable to interpolate observed values neither vertically nor horizontally for the present analysis because of sparse samples and of uniformity of properties of the Pacific Deep and Bottom Water (the Common Water). For the examination of the horizontal distribution of water properties, the basin area with bottom depths greater than 3800 m for the north of 24°20′N is divided into 20 parts by every 1°20′ of latitude and every 1°40′ of longitude centered at 31°N, 136°E (Fig. 1). For each of them potential temperatures and dissolved oxygen values sampled at depths of 3800 m to the bottom are shown symbolically according to ranges of observed values (Figs. 2–3).

The reversing thermometer yields the *in situ* temperature to an accuracy of about ±0.02 K in routine use. The conversion of *in situ* temperatures to potential temperatures was made through the table showing adiabatic cooling values against depth ranges (SUDO, 1985, Table 6); it adds the round off error of ±0.005 K to the measurement error. Therefore, the class interval of 0.02 K used in Fig. 2 may be too small for areas or cruises of sparse samples.

An anomalously low potential temperature (≦1.18°C) was detected at 3922 m, 29°04′N, 137°00′E in May 1977 (1.18°C, C4 in Fig. 2) for the first time in the north of 27°N except for 1.18°C at 4083 m, 32°55′N, 137°36′E in May 1976 (C1). The former had a high oxygen value of 3.60 ml l^{-1} (C4 in Fig. 3). In 1976 deep hydrographic observations for the north of 27°N were made only once (along 135°40′E, B areas, in November) or twice (along 137°30′E, C areas, in May and November). In May 1976 the potential temperature was 1.21°C or more below 3800 m along 137°30′E except for the above-mentioned C1 sample. Half a year later all of the samples collected below 3800 m along the same longitude showed a significant drop of 0.02–0.03 K (1.19–1.20°C); along 135°40′E it was 1.19–1.21°C excepting only one sample north of 32°N (B2).

In May 1977 all of the samples taken below 4200 m indicated 1.20°C or less and three of four stations had anomalously low temperatures and high oxygen values: 1.16°C, 3.64 ml l^{-1} at 4393 m, 30°41′N, 133°59′E (A3), 1.17°C, 3.82 ml l^{-1} at 4373 m, 28°00′N, 137°15′E (C5) and

1.18°C (no oxygen value) at 4284 m, 28°40′N, 137°28′E (C4). Because of lack of observations in B areas it is uncertain whether they formed a single cold water mass. In September all of the samples taken below 4000 m along 135°E between 28°N and 32°N had low temperatures of 1.16–1.18°C (B2–B4), while along 136°30′E the temperature below 4000 m was 1.24°C at 29°00′N (C4) and 1.19°C at 29°23′N (C3). The lowest potential temperature observed in the Shikoku Basin during 1975–1983 was 1.16°C that appeared at least twice in 1977. They are the above-mentioned A3 sample in May and at 4123 m, 31°56′N, 135°05′E (B2) in September. In November 1977 samples below 3800 m were taken only at three stations along 136°40′E north of 30°20′N (C2–C3). It is to be noted that none of the stations located north of 29°40′N, east of 136°E (C1–C3) throughout 1977 yielded an anomalously low potential temperature (≦1.18°C).

In 1978 only two deep stations were occupied along 137°E (C4 in February) before May. In May–July every deep water sample taken below 3800 m north of 27°N was warm (1.21–1.25°C) except one near the bottom in the southeastern part (1.20°C at 4186 m, 28°01′N, 138°01′E, D5). In September 1978 a low temperature of 1.19–1.20°C was observed at five of ten stations. In November an anomalously low potential temperature (1.17°C) was obtained at about 4000 m along 137°E north of 30°N (C1–C3). It should be kept in mind that all of the deep waters sampled below 4200 m were considerably warmer (1.22–1.27°C) than those at a depth of about 4000 m or less. It is probable that a single cold water mass a few hundred meters thick, centered at about 4000 m depth, was embedded in the deep water north of 30°N. This was the first appearance of the anomalously cold water to the north of 29°40′N, east of 136°E except for that in C1 area in May 1976.

For the area north of 27°N the occurrence of the anomalously cold water with a potential temperature of 1.18°C or less was limited in the period 1976–1978. As for the cold water sampled in May 1976, it is impossible to give any interpretation because of a small number of observations throughout 1975 to 1976.

It seems unlikely that the anomalously cold water entered the northeastern part of the basin (C1–C3) directly from the south. A possible explanation is that the area north of 29°N with bottom depths exceeding 4500 m, the northern part of which is called the Nankai Trough, is mostly limited to the area near the western periphery of the basin (Fig. 1). Its northeastern end reaches about 32°40′N, 136°40′E (C1). This suggests that the deepest basin water circulates clockwise and the old near-bottom waters found in November 1978 must have invaded from the north.

North of 27°N the cold water with a potential temperature of 1.21°C or less was not found in 1979 with the exception of two stations (1.20°C at 3817 m and 1.21°C at 4312 m, 28°01′N, 138°10′N, August, D5; 1.21°C at 4282 m, 29°51′N, 133°50′E, November, A3).

Few deep stations were taken in 1980. In July–September the potential temperature observed below 3800 m north of 27°N was all 1.19–1.22°C. Four of eight stations showed a low value of 1.19–1.20°C (three at 28–30°N along 137°E, C3–C5; one in the western part, 31°19′N, 133°41′E, A2). Though it is uncertain whether they formed a single cold water mass, this seems to indicate the second intrusion of the cold water mass into the basin. This is not so intense as the previous one in 1976–1977. In November the potential temperature below 3800 m was 1.22°C or more except for one sample (1.19°C at 4443 m, 30°00′N, 137°31′E, C3).

In 1981–1982 seven samples for the area north of 27°N had a low potential temperature of 1.19–1.20°C; three were at 30–31°N along 133°40′E (A3, at 3950 m, May 1981, at 4370 m, September 1981 and at 4126 m, August 1982); the other four were discretely distributed south of 30°N (at 3962 m, 30°00′N, 137°21′E, May 1981, C3, at 4276 m, 28°59′N, 135°37′E, September 1981, B4, at 3875 m, 28°20′N, 138°00′E, May 1982, D5 and at 4262 m, 29°02′N, 136°58′E, July 1982, C4). The two which occurred in May 1981 may be the remnants of the cold water inflow in 1980.

The deep hydrographic casts carried out in the Shikoku Basin by the Hydrographic Department ended with the cruise in February–March 1983. For the period after that only the *Ryofu Maru* data along 137°E were available. From these fewer observations, a cold water with a potential temperature of 1.20°C or less was not detected after November 1982.

The accuracy of dissolved oxygen values is estimated to be about ±0.05 ml l^{-1}. High oxygen concentrations (≧3.70 ml l^{-1}) were observed in the deep water of the Shikoku Basin at least twice for the period 1975–1983 (Fig. 3). In 1977 those high values were obtained separately along 137°E: 3.75 ml l^{-1} at 3949 m, 31°12′N, March (C2), 3.82 ml l^{-1} at 4373 m, 28°00′N, May (C5) and 3.72 ml l^{-1} at 4593 m, 25°00′N, July (C7). The second one of the above, which had an extremely high value, was taken at 177 m of the bottom, accompanied by an anomalously low potential temperature (1.17°C). Nine of ten samples of high values (≧3.60 ml l^{-1}) had low potential temperatures (≦1.20°C). This suggests that the above oxygen-rich waters were the fresher, cold bottom waters invaded from the south.

The second increase in deep water oxygen concentration occurred corresponding to the intrusion of the cold deep or bottom water in the second half of 1980 to the first half of 1981. Its beginning was presented by the *Ryofu Maru* station at 25°N, 137°01′E in July 1980: 1.20°C, 3.62 ml l^{-1} at 3927 m, 1.18°C, 3.65 ml l^{-1} at 4422 m and 1.17°C, 3.72 ml l^{-1} at 4918 m (at 192 m of the bottom). Though deep stations occupied in January–May 1981 were limited to two areas north of 30°N, along 133°40′E (A2–A3) and along 137°00′E or 137°20′E (C1–C3), only one of 17 samples for the north of 29°N was a little poor in oxygen concentration (3.54 ml l^{-1}) and three showed high values (3.71–3.76 ml l^{-1}); all of the values below 4000 m were 3.64 ml l^{-1} or more. This oxygen increase on a large scale did not continue until summer. Only one of 13 stations taken north of 28°20′N in July–September 1981 yielded a high oxygen concentration (≧3.60 ml l^{-1}) and four out of 16 did in November–December.

In March 1982 ten stations were made along 133°50′E (A2–A3), along 135°50′E (B1–B4) and along 137°50′E (D1–D4); high oxygen values (3.63–3.80 ml l^{-1}) were obtained except for the southernmost one (29°12′N, 137°48′E, D4). For the major part of the northern area (*e.g.*, A2, B3, and D2) high values of 3.60–3.71 ml l^{-1} were continuously or intermittently observed until November 1982 or March 1983. In particular, in the northwesternmost area (A2) all of the measurements below 4000 m in 1981–1982 were more than 3.60 ml l^{-1}. On the contrary, none of three hydrographic casts carried out at 25°N, 137°E during July 1981–July 1982 showed such a high oxygen concentration. Therefore, it seems unlikely that the oxygen increase in March 1982 was due to the deep water invasion directly from the south. Possibly the oxygen-rich bottom water having entered the basin in the spring of 1981 ascended by several hundred meters and appeared in the northeastern area of the basin at some time of the autumn of 1981 to the spring of 1982. However, available hydrographic data fail to give definite and reliable information on the cause of this oxygen increase.

In 1983 the deep water below 3800 m at 25°N, 137°E (C7) indicated a significant increase in dissolved oxygen, but its effect on the Shikoku Basin water is unknown.

It is shown from a comparison between Fig. 2 and Fig. 3 that higher oxygen values are not always accompanied with lower potential temperatures for the deep basin waters. Each of divided areas given in Fig. 1 mostly has only one to three samples for the same cruise. Therefore, if for each of divided areas the potential temperature-dissolved oxygen relation is plotted by the present data from various cruises, it must be widely dispersed because of systematic errors, even if they are small. Nevertheless, in the southernmost part of the 137°E section (C7) both properties have some inverse correlation.

Though stations are limited to the northern area of the basin, the data taken from R.V. *Thomas Washington* in June–July 1971 (Scripps Institution of Oceanography, 1977) are very useful to examine the relation for the deep water of the Shikoku Basin because of a large number of samples. There is a distinct relation between both properties for the area of 31°00′–32°20′N and 134°20′–136°00′E (B2); north of it (B1) the correlation is discernible as well (Fig. 4). For other three areas (A2, C1 and C2) the relation hardly exists. Besides, about half of the B2 samples had low potential temperatures of less than 1.20°C and all of them showed high oxygen values of more than 3.60 ml l^{-1}. The

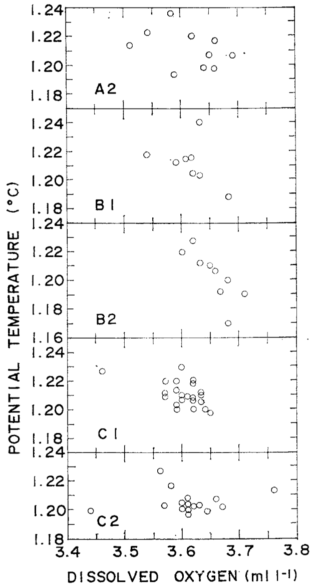

Fig. 4. Potential temperature-dissolved oxygen relation for samples taken below 3800 m from *Thomas Washington* in June-July 1971. Area symbols are shown in Fig. 1.

distribution is most scattered in A2 area and most concentrated in C1 area. These imply that the deep or bottom water mass which has entered the Shikoku Basin from the south will reach the northwestern part of the basin at an early stage. After that it slowly spreads clockwise in the northern area at least north of 31°N splitting into cold or oxygen-rich water patches (B1, A2 and C2) and mixing mainly with the overlying basin water (C2 and C1).

3. Deep water property variations along 137°E

To trace the origin of the anomalously low temperature and the high oxygen concentration in the deep water of the Shikoku Basin, both property values interpolated for the 4000 m depth at 30°, 25°, 20° and 15°N along 137°E are plotted as a time series during 1976-1983 (Figs. 5-6). At 25°N interpolated values for 4500 m are also plotted because the bottom depth is several hundred meters geater than that at 30°N or 20°N. In addition, vertical distributions of properties below 2400 m at four stations along 137°E are depicted (Figs. 7-9).

The 4000 m potential temperature at 30°N, 137°E, which was usually 1.22-1.23°C, dropped

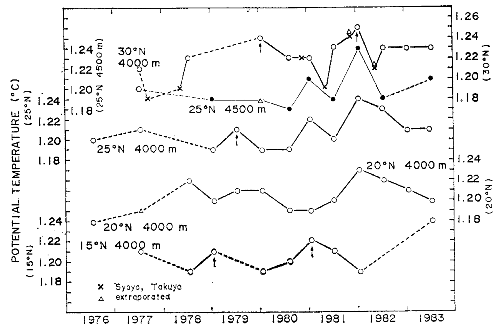

Fig. 5. Time series of potential temperature interpolated for 4000 m depth at 30°N, 25°N, 20°N and 15°N and for 4500 m depth at 25°N along 137°E. Stations were taken from *Ryofu Maru* unless specified.

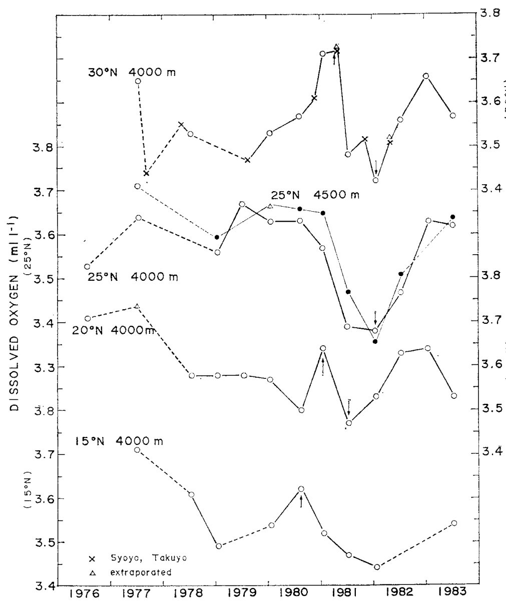

Fig. 6. As in Fig. 5 except for dissolved oxygen.

to 1.18-1.19°C in September 1977-May 1978 and in May 1981, while it rose to 1.25°C in January 1982 (Fig. 5). Though the rise seems to have occurred concurrently at stations of 30° to 20°N, temperature falls were not always clear at 25°N and south. The 4500 m temperature at 25°N was usually 1.19°C, occasionally rising to more than 1.20°C, but it was not below 1.18°C. The 4000 m temperature fluctuated with a range of about 0.05K at 25°N and south.

It is a surprise to find that there appears to be a definite inverse correlation between the

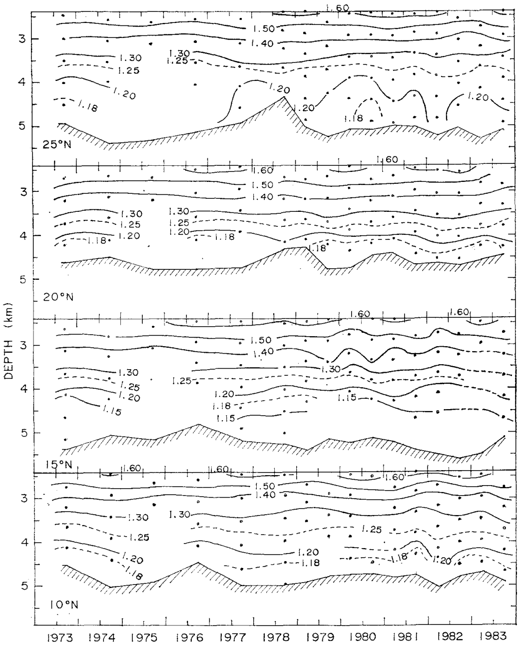

Fig. 7. Depth-time diagram of potential temperature below 2400 m at 25°N, 20°N, 15°N and 10°N along 137°E. Stations were taken from *Ryofu Maru* usually in July and in addition, in January for 1979 and after.

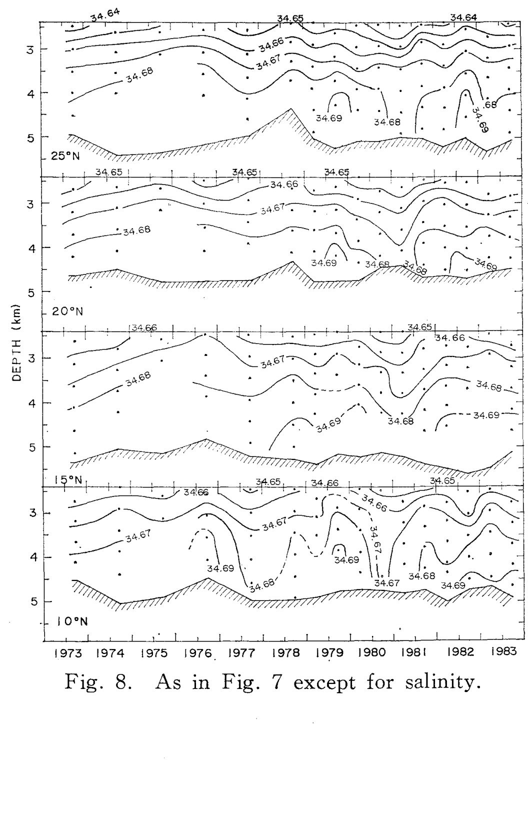

Fig. 8. As in Fig. 7 except for salinity.

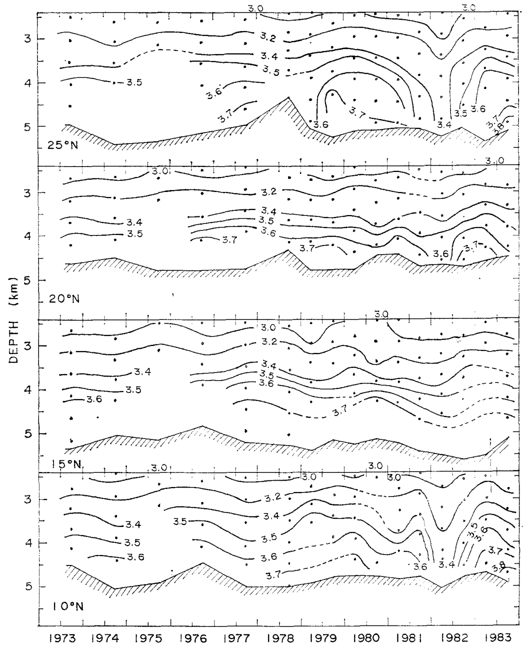

Fig. 9. As in Fig. 7 except for dissolved oxygen.

4000 m potential temperature at 20°N and that at 15°N. The sea bottom at 15°N, 137°E and vicinities, where a depression is formed, is several hundred meters greater than that at 20°N and vicinities. Figure 7 shows that a cold bottom water mass with a potential temperature of 1.15°C or less always lay to a thickness of more than several hundred meters at 15°N, 137°E, though observations were scarce below 4000 m. Its thickness varied greatly. Therefore, the upper portion of the water mass accumulated on the depression may be forced periodically or sporadically to move and be replaced by a warmer water mass. This is a plausible explanation of the inverse correlation of 4000 m potential temperatures between at 20°N and 15°N shown in Fig. 5, but it cannot be verified owing to the insufficiency of observations. A noticeable undulation of isotherms is illustrated below 4000 m at 25°N, 137°E; however, its potential temperature rarely dropped to less than 1.18°C. It is probable that the cold bottom water flows northward on the western flank of the basin, west of 137°E, at 25°N.

The time series of dissolved oxygen concentration for 4000 m at 30°N, 137°E resembles that at 20°N rather than that at 25°N (Fig. 6).

As mentioned above, the northward flow of the deep water must have avoided the station at 25°N, 137°E where the bottom depth is greater than that at both sides (20°N and 30°N) along the longitude. The inverse correlation of 4000 m oxygen values between at 20°N and at 15°N is not so conspicuous as that for potential temperatures. The peak presented at 15°N in July 1980 seems to have propagated northward and to have reached 30°N in May 1981, being away from 137°E at 25°N. If the case occurred, it travelled from 15°N to 30°N at a rate of about 0.06 m s^{-1}. For the potential temperature both of maximums shown in January 1979 and in January 1981 at 15°N seem to have reached 30°N a year later (Fig. 5); the average travelling speed was about 0.05 m s^{-1}, if the movement existed. A layer of more than several hundred meters of the bottom at 15°N, 137°E was occupied by an oxygen-rich bottom water with a value of 3.70 ml l^{-1} or more as well as the cold bottom water (Fig. 9).

The salinity variation seems to be much complicated (Fig. 8). It may be to a certain extent due to systematic measurement errors, because isohalines undulate greatly in the upper waters as well. A noteworthy feature in Fig. 8 is the salinity decrease that occurred concurrently at 15°N and north in January 1981.

4. Salinity and dissolved oxygen variations on the isothermal surface

Since the oxygen variation did not always correlate with the temperature variation in the deep or bottom water of the Shikoku Basin, the temperature-oxygen relation must have varied appreciably in the basin. But this is difficult to examine because water property ranges are small and measurement errors are relatively large at greater depths. To find variations in property relation, isothermal surfaces for potential temperatures of 1.3°C and 2.0°C were selected (Figs. 10 and 11).

For 1.3°C surface (at a depth of about 3000-3300 m), both salinity and dissolved oxygen distributions show similar periodical variations after 1978, being maximum values from late 1979 to early 1980 and in 1982. For 2.0°C surface (at a depth of about 1700-2000 m), the salinity variation is similar to that for 1.3°C;

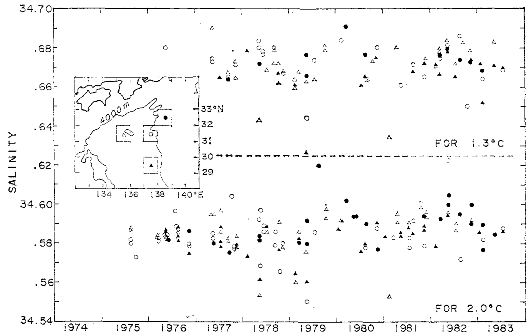

Fig. 10. Salinity on the isothermal surfaces for potential temperatures of 2.0°C and 1.3°C in selected 1°×1° areas shown in the inserted chart.

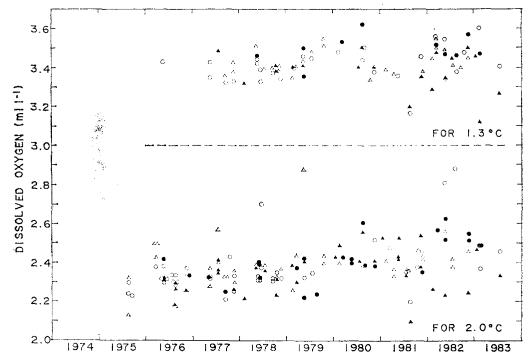

Fig. 11. Dissolved oxygen on the isothermal surfaces for potential temperatures of 2.0°C and 1.3°C in selected 1°×1° areas shown in the inserted chart in Fig. 10.

though dissolved oxygen values were dispersed after 1981, they were generally high in 1982-1983 except for the southeastern part (29-30°N, 137-138°E).

The dissolved oxygen maximums in 1982 for 1.3°C surface occurred early in 31-32°N, 135-136°E area (included in B2 area shown in Fig. 1) and late in 32-33°N, 138-139°E area (included in D1-D2 areas). Therefore, it may be concluded that they were brought through the oxygen increase in the lower water, probably the marked oxygen increase in January-May 1981 (A3 and C3 in Fig. 3). If it had propagated from the south, it took about two years to get to a depth of 3000 m in the northeastern corner of the Shikoku Basin from a depth of 4000 m at 15°N, 137°E. It seems likely that this oxygen increase had an effect on the upper water up to 2000 m or less in the northeastern part of the basin.

On the contrary, a sudden drop in the second half of 1981 on both isothermal surfaces took place down to the bottom north of 20°N at the same time (Figs. 6 and 9). The decrease was remarkable east of 137°E. Though Fig. 6 indicates the 4000 m oxygen minimums at 30°N and 25°N in January 1982, the differences from the preceding values are small. This transient sharp decrease in dissolved oxygen for fixed potential temperature values on an extensive scale both horizontally and vertically may be related to the occurrence of the southward detour of the Kuroshio path in November 1981.

5. Discussion

Normal property values of the deep water of the Shikoku Basin are not known definitely. Prior to the deep hydrographic casts made by the Hydrographic Department starting in 1976, three special cruises for the survey of the Kuroshio were carried out in the northern part of the basin during 1965–1975. For this reason a comparison of historical data is made for the north of 30°N (Table 1).

Within 250 m of the bottom or below 4500 m the above three surveys indicates low mean potential temperatures of 1.20–1.21°C with small dispersion because of single cruises. The mean for 1977 is slightly lower than the earlier means. However, for the upper water, the difference between the mean for the early three surveys (1965–1975) and that for the late observations (1979–1982) is only 0.01–0.02 K; in 1976–1977 the upper water was remarkably cooler. The lowest potential temperatures were 1.187°C (doubtful) or 1.200°C in 1965, 1.17°C in 1971 and 1.20°C in 1975.

In the deep water below 3800 m there was a considerable year-to-year variation in dissolved oxygen concentration. Though it is difficult to determine the normal absolute values, under the normal condition the value within 250 m of the bottom or below 4500 m seems to be about 0.04 ml l^{-1} higher than that for the overlying water. This difference was occasionally reduced with larger increase in the upper water than in the lowest water. Therefore, it may be reasonably concluded that the state was normal in 1965, 1977, 1978 and 1983. The 1971 values were apparently higher in dissolved oxygen and somewhat lower in potential temperature; possibly a fresh bottom and deep water had flowed into

Table 1. Potential temperatures and dissolved oxygen concentrations below 3800 m north of 30°N in the Shikoku Basin.

Year	Potential temperature						Dissolved oxygen					
	Within 250 m of the bottom or below 4500 m			Above 4500 m and above 250 m of the bottom			Within 250 m of the bottom or below 4500 m			Above 4500 m and above 250 m of the bottom		
	No. obs.	Mean (°C)	Std. dev. (K)	No. obs.	Mean (°C)	Std. dev. (K)	No. obs.	Mean (ml l^{-1})	Std. dev. (ml l^{-1})	No. obs.	Mean (ml l^{-1})	Std. dev. (ml l^{-1})
1965[1]	16	1.210	0.011	13	1.222	0.014	7	3.569	0.032	8	3.526	0.038
1971[2]	34	1.202	0.008	36	1.216	0.010	31	3.624	0.047	34	3.607	0.052
1975[3]	6	1.207	0.005	8	1.221	0.006	5	3.518	0.058	8	3.488	0.059
1976	8	1.210	0.016	7	1.204	0.016	7	3.583	0.089	7	3.573	0.038
1977	9	1.199	0.021	10	1.203	0.019	8	3.575	0.064	10	3.538	0.084
1978	30	1.217	0.022	24	1.225	0.015	30	3.570	0.041	22	3.538	0.067
1979	5	1.236	0.011	22	1.238	0.013	5	3.532	0.077	23	3.495	0.055
1980	7	1.223	0.019	13	1.235	0.021	7 (6	3.664 3.585	0.214 0.045)*	13	3.561	0.047
1981	18	1.231	0.016	24	1.237	0.015	18	3.546	0.115	24	3.599	0.077
1982	13	1.228	0.011	18	1.237	0.018	13	3.641	0.074	19	3.571	0.096
1983	2	1.220	0.014	7	1.231	0.013	2	3.590	0.028	7	3.544	0.057

* a doubtful value of 4.14 ml l^{-1} is excluded.

[1] CSK 31K001 (*Atlantis II*) (JAPAN OCEANOGRAPHIC DATA CENTER, 1966),

[2] ARIES Leg VI (*Thomas Washington*) (SCRIPPS INSTITUTION OF OCEANOGRAPHY, 1977),

[3] KH-75-5 (*Hakuho Maru*) (OCEAN RESEARCH INSTITUTE, 1978).

the Shikoku Basin in the year or shortly before. Such an oxygen-rich water intrusion occurred in 1976 and in 1980–1982 as well, but the latter was complicated owing to a transient decrease in 1981. The reason why the oxygen value decreased in 1975 and 1979 cannot be understood.

The direct source of the anomalously cold or oxygen-rich water occasionally found below about 4000 m in the Shikoku Basin can be traced at least to 15°N (Figs. 7 and 9). However, the mechanism of its formation and spreading to the north is still unknown. Such a shift in the potential temperature-dissolved oxygen relation as observed in the Shikoku Basin in 1980–1982 must have originated in the south. The significant hydrographic response to modest short-term climatic forcing has been pointed out for the northern North Atlantic (*e.g.*, BREWER *et al.*, 1983; SWIFT, 1984). However, the origin cannot be found in the North Pacific because neither the deep water nor the bottom water is not formed there.

It is uncertain whether there exists a steady deep circulation in the basin showing a wide variation in water property or the basin flow is sporadic and every time it happens the property distribution is disturbed. Possibly both movements coexist. One of the most probable deep currents based on direct measurements in the Shikoku Basin is a westward current above several hundred meters of the bottom at the northern edge of the basin along 136°15′E (FUKASAWA *et al.*, 1985) or 136°30′E (TAFT, 1978). But TAFT (Table 2 and Fig. 14a) presented an eastward bottom current of about 0.05 m s^{-1} at 32°40′E. The result of the present analysis indirectly confirms the eastward current below about 4000 m in the northern part of the basin.

6. Conclusion

Below about 4000 m in the Shikoku Basin there seems to be a steady or unsteady northward flow along the western boundary; it circulates clockwise off the continental slope slowly moving upward and renewing the deep basin water. In 1976–1977 an anomalously cold deep or bottom water with a corresponding high dissolved oxygen concentration intruded into the basin. However, a remarkable increase in dissolved oxygen that occurred below about 3000 m in 1980–1982 was accompanied only by a subtle decrease in potential temperature. The direct source of such an anomalously cold or oxygen-rich deep water can be traced at least to 15°N; at 4000 m level it may travel from 15°N to 30°N in about one year. The transient sharp decrease in dissolved oxygen that took place at least below 2000 m in the eastern area north of 20°N during the second half of 1981 to early 1982 must be connected with the occurrence of the southward shift of the Kuroshio path in November 1981.

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四国海盆約 4000 m 以深の深層水の特性の変動

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要旨: 四国海盆内 3800 m 以深のポテンシャル水温と溶在酸素の分布の，1975 年から 1983 年の間における変動を調べてみた。海盆の西縁の約 4000 m 以深には定常あるいは非定常の北上流があり，海盆北部では，大陸斜面の南側を時計まわりに循環しながらゆるやかに上昇し，海盆内の深層水を更新しているらしい。1976年から1977年にかけては，著しく低温で溶在酸素の多い底深層水が海盆内に流入した。1980 年から 1982 年にかけても，3000 m 以浅にまで及ぶ深層水での溶在酸素の著しい増大がみられたが，底深層における水温の低下はごく僅かにとどまった。これらの低温高酸素水は 15°N 以南に直接の起源があり，4000 m 深では 15°N から 30°N まで約1年で到達するとみられる。なお，1981年後半から1982年初めにかけて，20°N 以北の東部では少なくとも 2000 m 以深の全層にわたり，溶在酸素の一時的な急低下がみられたが，これは1981年11月の黒潮大蛇行の発生と関連があるらしい。